REFURBISHMENT OF THE JET PROPULSION LABORATORY'S LARGE SPACE SIMULATOR*

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ABSTRACT/RESUME

The Caltech Jet Propulsion Laboratory's (JPL) large space simulator has recently undergone a major refurbishment to restore and enhance its capabilities to provide high fidelity space simulation. This facility was constructed in 1961 and was modified in 1965 to include an off-axis solar simulation system. Since then the facility has been used extensively for systems level testing of planetary, orbital, and geosynchronous spacecraft. The nearly completed refurbishment has included: upgrading the vacuum pumping system by replacing old oil diffusion pumps with new cryogenic and turbomolecular pumps; modernizing the entire control system to utilize computerized, distributed control technology; replacing the Xenon arc lamp power supplies with new upgraded units; refinishing the primary collimating mirror; and, replacing the existing integrating lens unit (ILU) and the fused quartz penetration window.

Keywords: JPL, Space Simulator, Mirror, Cryopump, Solar Simulation, Thermal/Vacuum.

1. INTRODUCTION

JPL's large space simulator (see Figure 1) has been in service since the early days of the space program and has provided high fidelity simulation of the space environment for the development and testing of flight-worthy space hardware (see Figure 2). Being one of the very first large space simulators built in the United States, the facility utilized contemporary 1960's technologies for vacuum pumping, system controls and solar simulation. Over the years, several modifications have been made to the facility to maintain and upgrade its operational proficiency. Time, age and use finally decreed that a major refurbishment of the chamber and its operating systems was needed. This paper describes some of the details of this refurbishment project.

2. FACILITY DESCRIPTION

The JPL space simulator is a side-opening vertical cylinder 26 meters high and 8.2 meters in diameter with a rectangular access door measuring 4.6 meters wide by 7.6 meters high and a nominal operating pressure of 1 x 10^{-6} torr. The walls and floor are lined with cryogenically-cooled black aluminum panels that can be temperature-controlled through a range from -185 °C to +200 °C. An off-axis solar simulation system utilizes 37 xenon arc lamps, each capable of operating at 30 Kw, and a selection of two collimating mirrors and two integrating lens units (ILU) to provide a variety of beam sizes and intensities as described in Table 1. The chamber can be evacuated and cooled from atmospheric conditions to its ultimate pressure and temperature in about 1 hour, 30 minutes and can be returned to ambient conditions in about 2 hours, 30 minutes.

3. FACILITY MODIFICATIONS

The nearly completed facility refurbishment included: upgrading the vacuum pumping system by replacing oil diffusion pumps with cryogenic and turbomolecular pumps (see Figure 3); modernizing the entire control system to utilize computerized, distributed control technology; replacing the xenon arc lamp power supplies with new upgraded units; refinishing the primary collimating mirror; and, replacing the integrating lens unit and the fused quartz penetration window. The general contractor for this project was Pittsburgh Des Moines Steel Company (PDM).

Table 1. Solar Simulation System Configurations

Configuration		Solar Beam Diameter	Maximum Solar Beam Intensity (Note #1)
Collimating Mirror Diameter	ILU #	Meters	Solar Constants (Note #2)
7.01 m (23-Ft)	#2	4.57 m	4.2
	#4	5.64 m	2.7
4.57 m (15-Ft)	#2	2.59 m	13.0
	#4	3.35 m	7.8

Note #1: With 37 lamps at 30 kW.
Note #2: 1 Solar Constant = 1354 watts/m^2

* The refurbishment described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

3.1 Solar Simulation System Description

The primary driving force for the refurbishment project described in this paper was the reduced performance of the solar simulation system. As the result of corrosion of the nickel plating on the 7.01-m diameter collimating mirror surface, it had lost about 40% of it's rated reflectivity. This corrosion occurred early in the mirror's life and was caused by residual material on the surface of the mirror reacting with water vapor. Even though the mirror was subsequently cleaned, re-aluminized and protected against further damage many years ago, the earlier corrosion could be repaired only by removing the damaged nickel surface and replating the thick aluminum substrate with a new nickel layer. To provide this new nickel layer, an electroless nickel process was used in preference to electroplating to provide a harder material surface (Rockwell 60) on which to grind and to produce a brighter polished finish.

3.1.1 Collimating Mirror Refurbishment

The 7.01 meter diameter, 13,500 kilogram (15 ton) mirror is the primary collimating element of the solar simulation system optics. It is mounted at the top of the chamber and is cooled by gaseous nitrogen to -75 °C during operation of the solar simulation system. Tinsley Laboratories, the contractor responsible for grinding and polishing the original mirror, was selected to perform the mirror refinishing work.

A large grinding and polishing machine, designed by Tinsley and fabricated by L & F Machine Works, was installed adjacent to the space simulator in a building which was built specifically to house the mirror refinishing equipment. The mirror was removed from the chamber, transported to the refinishing building and mounted face up underneath the grinding/ polishing machine in preparation for the nickel removal process. A large 10 foot diameter grinding tool with cast iron grinding pads was used to remove the electroplated nickel. The machine was designed for three degrees of movement; rotational, radial through an arc and lateral across the surface (see Figure 4). Machine movements were computer-controlled using a Tinsley-generated program.

In August 1992, grinding to remove the old nickel-plated surface commenced. After the nickel removal, the aluminum substrate was ground to re-establish a uniform spherical radius of curvature at 1200 inches (30.48 meters). This substrate grinding period lasted about 20 weeks.

The electroless nickel plating was performed by EMF using the mirror itself as the plating bath container. The grinding machine, reconfigured as the plating bath agitator, was fitted with multiple spray nozzles and jets to-distribute plating solutions over the mirror (see Figure 5). Counter-rotating paddles were used to circulate the plating bath. The solutions were swept to the outer edge of the mirror into a perimeter dam then recirculated to conditioning tanks outside the building where solution concentrations and temperatures were adjusted to strict specifications. The electroless plating process is highly dependent upon tight control of the plating solution concentration and temperature.

After some experimentation with the temperature control system for the mirror, and one unsuccessful plating attempt, the mirror was successfully plated with an electroless nickel layer about 0.014 inch (0.036 cm) thick. The new surface was reground to the desired radius of curvature and then final polishing was performed. The polished nickel surface has a reflectivity of about 65%. The mirror surface reflectivity will be increased to 85 to 90% following reinstallation of the mirror into the chamber (Ott/93), and re-aluminization of the surface in situ by chemical vapor deposition under vacuum.

3.1.2 Collimating Mirror Re-Aluminizing

Re-aluminization of the mirror surface in the chamber will be done in Ott-Nov/93. An array of three electron guns will be used to heat a crucible of aluminum located inside the vacuum chamber below the mirror. The volume of aluminum in the crucible will be kept constant by continuously feeding aluminum wire to it. A remotely actuated shutter will shield the mirror from the crucible and aluminum vapor until the proper vapor deposition rate has been established experimentally. When the shutter is opened, a uniform film of vapor-deposited aluminum, about 1000-1200 Angstroms thick, will be applied to the mirror surface. The walls of the chamber will be lined with mylar covering to shield them from aluminum vapor deposition. This process has been executed successfully at JPL several times. The realuminization process is expected to be completed in Nov/93.

3.1.3 Lamp Power Supplies and Igniters

Prior to this recent chamber refurbishment, each of the 37 xenon arc lamps were powered by three 12 Kw sources operating in parallel (each delivering 1/3 of the required load) to provide the 30 Kw needed. These sources were replaced with 37 individual power supplies, provided by Electronic Measurement, inc., each capable of delivering 33 Kw (10% reserve). Also installed were 37 new high voltage igniters, which were manufactured by LT Associates and provide the lamp ignition pulse. The high voltage relays were supplied by Jennings Corporation. The power sources are located about 25 meters from the lamps, Accurate measurement of the lamp voltage is required to ensure that the lamps are not allowed to exceed the manufacturers warranty. A voltage tap, isolated from the high voltage pulse required for ignition, was provided at the lamp electrode to satisfy this measurement/ monitoring requirement.

3.1.4 Integrating Lens Unit (ILU)

The off-axis optical system used to provide solar simulation in the JPL space simulator uses a 19 channel ILU mounted optically just upstream of the penetration window. The ILU consists of a condensing lens array made up of 19 hexagonal biconvex lenses followed by a projection lens array made up of 19 hexagonal piano-convex lenses (see Figure 6). The radiation energy from the lamp array passes through the ILU to form a uniform beam, is projected through the penetration window into the chamber onto the collimating mirror, and is reflected by the mirror into the test volume. The ILU, which is water cooled, is another critical element of the solar simulation system. A new ILU, which incorporates some design improvements to expand the useful uniform beam diameter, is being fabricated and will be installed soon.

3.1.5 Penetration Window

The penetration window is of ultimate criticality since the vacuum of the space simulator and the survival of the test specimen is dependent upon the structural integrity of this window. The existing penetration window, made from fused quartz, has been in service in the chamber for about 20 years. Concern has been expressed over the expected life of such a critical optical component operating in the space and solar simulation environment. To allay such concerns, the existing window will be removed, inspected and refinished as needed so it may be used as a spare. It will be replaced with a new penetration window made from fused silica. The new window diameter of 28.5 inches (72.4 cm) will be slightly larger than the 26.5 inch (67.3 cm) diameter of the existing window to accommodate the increased diameter of the light projected from the new ILU.

3.2 Vacuum System Description

A typical pumpdown of the chamber will begin by evacuation from atmospheric pressure to 70 torr in 10 minutes utilizing a two-stage axial compressor. For the next 60 minutes, a mechanical pumping system, consisting of four Stokes 1722} IC combinations and two large Roots t ype blowers (Stokes 1713), willl lower the pressure to the 5 x 10^{-2} torr range, the cross-over threshold where the cryogenic pumps take over the pumping duty, This phase of pumping is referred to as "roughing" and requires about 70 minutes.

During the roughing period, a]iquid-nitrogen-coohd baffle will be chilled to prevent mechanical pump oil vapors from backstreaming into the vacuum chamber. After each evacuation, this baffle, or cold trap, will be warmed to ambient temperature and any condensed liquid will be drained.

The cross-over from the mechanical roughing system to the new cryogenic pumping system will be accomplished by opening the high vacuum valves when the pressure is at about 5 x 10-2 torr. Ten 45,000 liter/sec cryogenic pumps are available for the final stage of evacuation to an ultimate pressure of 1 x 10^{-6} torr. The final evacuation from 5 x 10"2 torr to 1 x 10-6 torr will take about 20 minutes. Thus, the total evacuation period will be about 1 hour, 30 minutes .

Two 2200 liter/sec turbomolecular pumps have been installed to be used when high loads of helium or hydrogen are encountered. Also, these pumps can be used for leak detection of the chamber and the nitrogen shrouds.

The new cryogenic pumps were manufactured by Cry-O-Vac Inc. The turbomolecular pumps are Balzer products. The high vacuum gate valves were built by Torr-Vac Inc. Figure 3 illustrates a typical installation of the new cryopumps and high vacuum valves.

3.3 Control System Description

The old hard-wired control system is being replaced with a computerized, distributed control system using General Electric-Fanuc Genius components. The new control panels include large graphic display features to aid operators in visualizing all control functions (see Figure 7). To protect against single component failures during test operations, the new system includes a continuously on-line backup CPU to provide complete redundancy for all control functions and double redundancy for critical items. The controls can be actuated either by switches on the control panel or by keystrokes on a PC keyboard.

The solar simulation system control panel display includes the total power load of the entire operating array as well as 37 individual displays showing voltage, ampere, and kilowatt measurements for each lamp. Also displayed is the solar beam intensity as measured by a Kendall Cone radiometer. Beam intensity is controlled by automatically compensating for variations in input voltage from the incoming electrical sour-cc.

4.0 SUMMARY

In summary, the refurbishment of the large JPL space Simulator has been accomplished so far with few difficulties. Even though the first unsuccessful electroless nickel plating of the collimating mirror caused some schedule delay, the finished surface has met all expectations. No other schedule delays have occurred except that the installation of the new control system is taking longer than anticipated. Currently, it is projected that the facility will be available for spacecraft testing by Feb/94. Emperical parametric test data will be gathered during the upcoming acceptance testing and should be available in Jan/94.

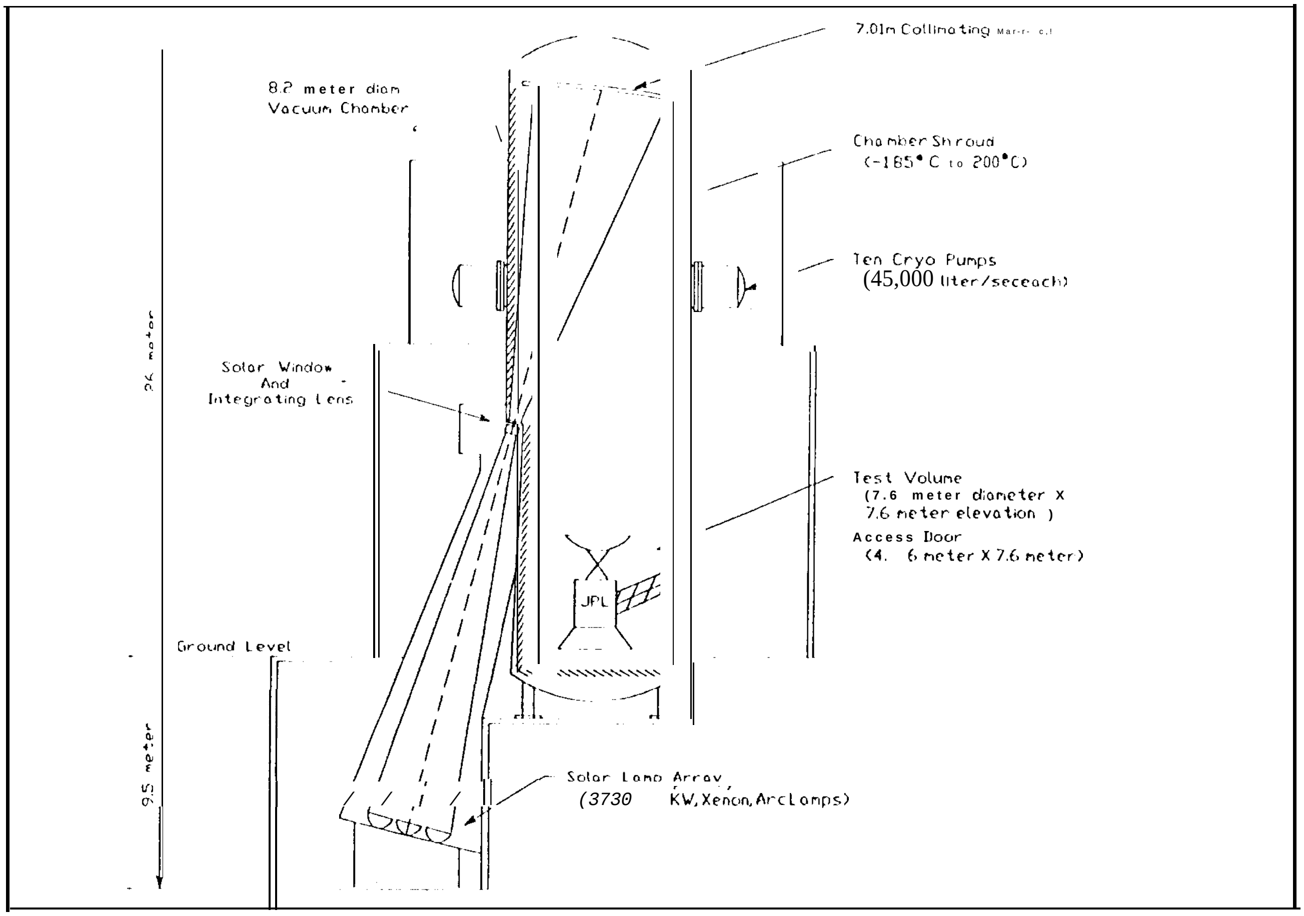


Figure 1. The JPL Large Solar Simulator Configuration.

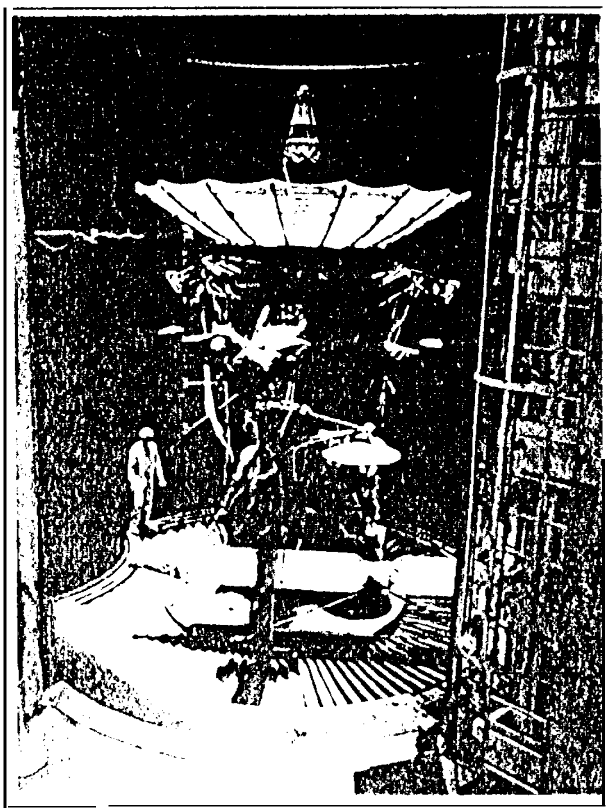


Figure 2. The Galileo Spacecraft Mounted in the JPL Large Space Simulator.

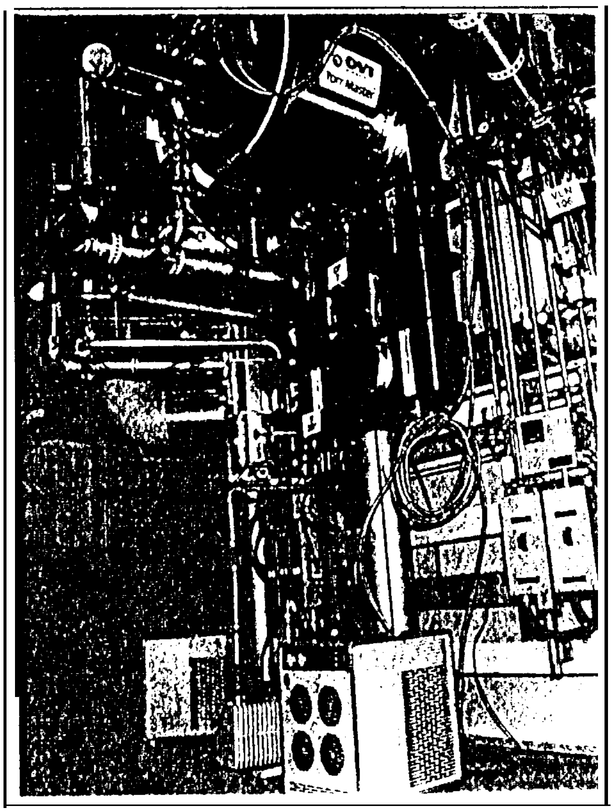


Figure 3. The New Cryopump and High Vacuum Valve installation.

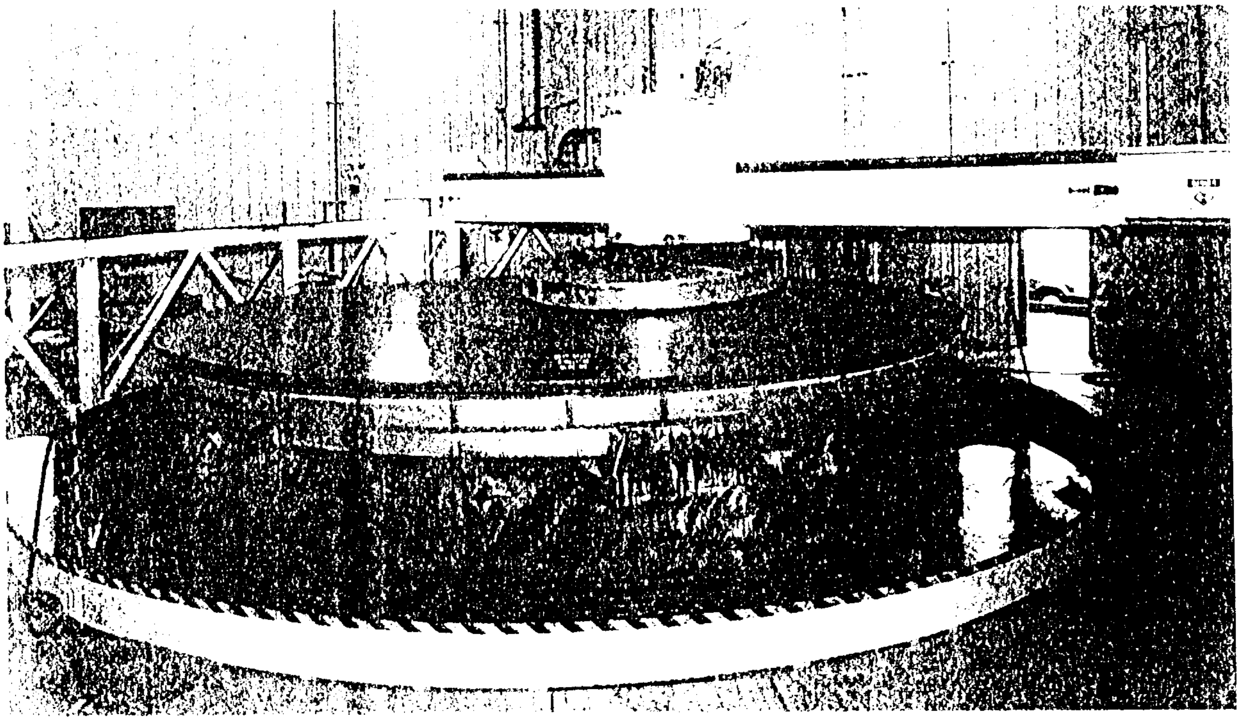
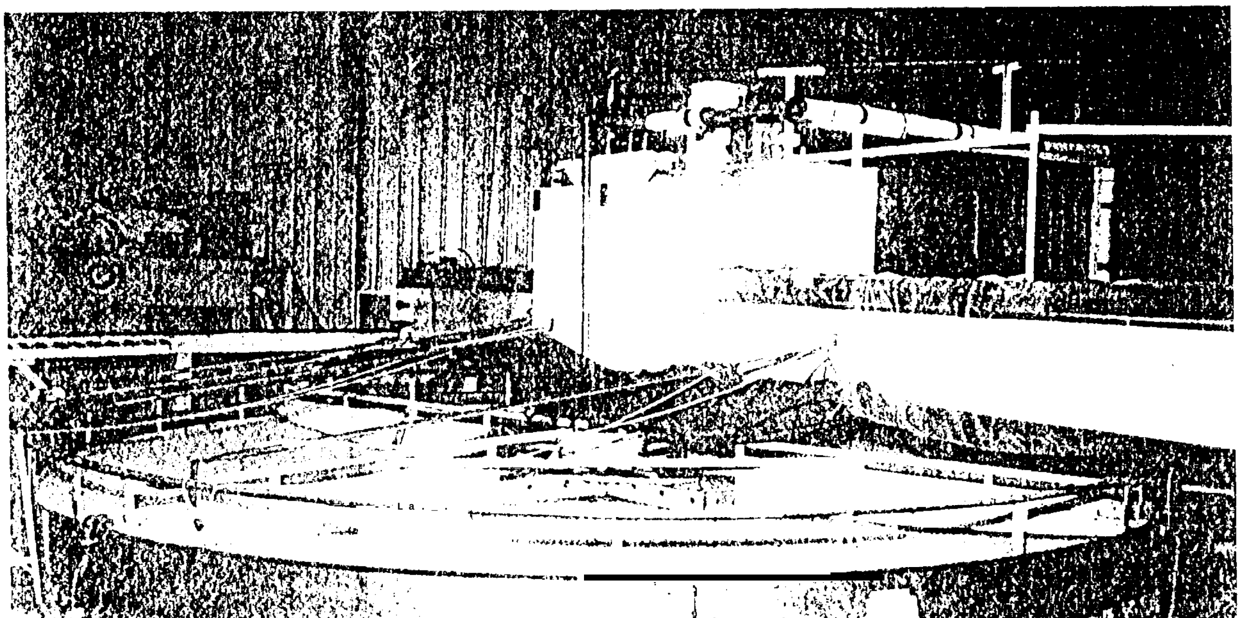


Figure 4. The Grinding/Polishing Machine Used for Refinishing of the Collimating Mirror



igure 5. The Plating Bath Agitation Machine [illegible]

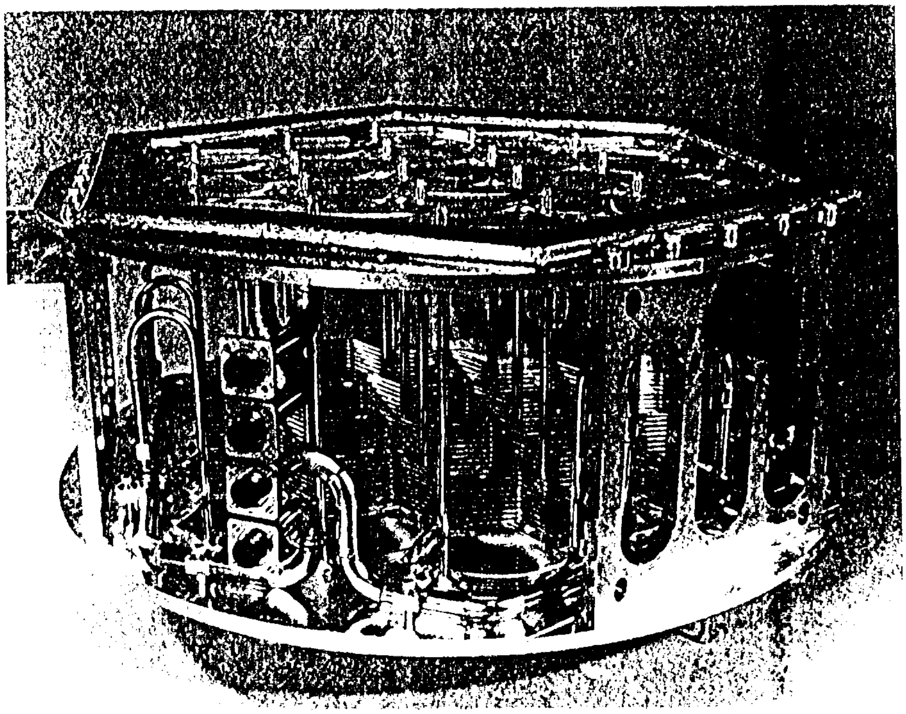


Figure 6. The Integrating Lens Unit Configuraton.

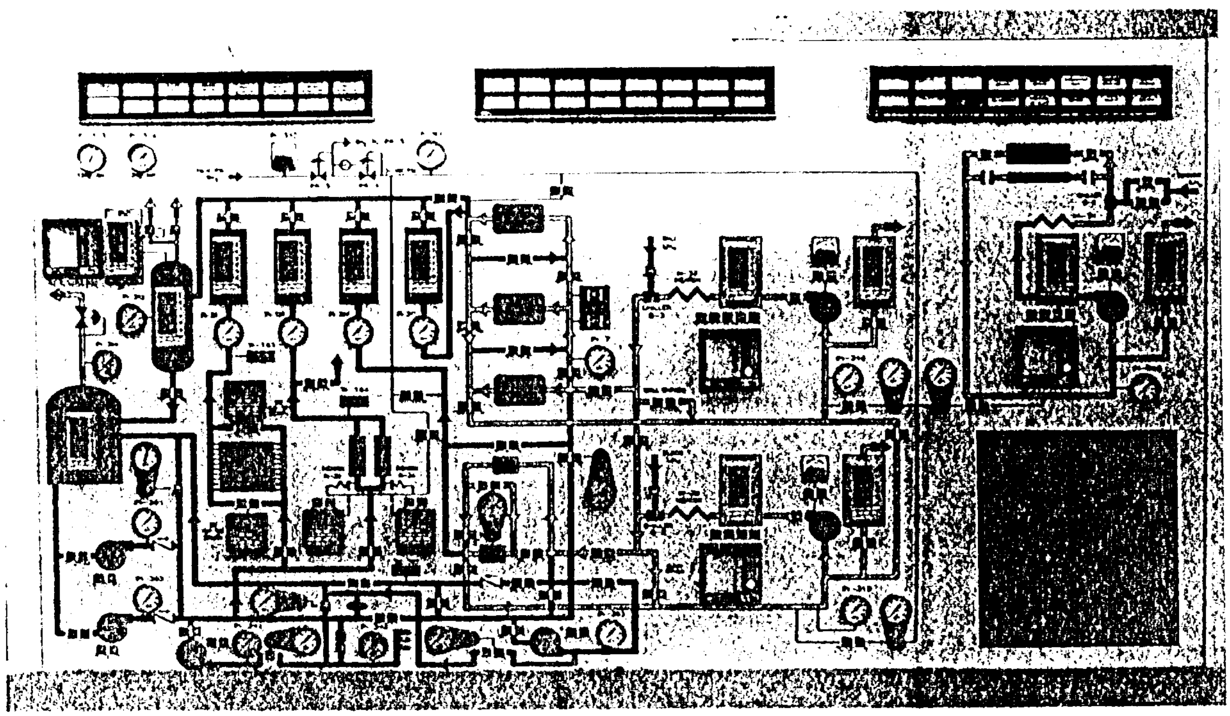


Figure 7. The New Graphic Control Panel for Thermal System Operations.

JET PROPULSION LABORATORY

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Abstract for *Seven ty--w Yews of Hirayama Families: The Role of Collisions in the Solar System History.*

Tumbling Asteroids

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Burns and Safronov *(Mon. Not. R. Astron. Sot. 16S,* **403-411, 1973)** estimated the damping timescale of rotational wobble for asteroids, and concluded that all asteroid rotations then known should be damped to a state of principal-axis rotation about the axis of maximum moment of inertia. 1 have re-examined this question in the light of some more recently determined cases of very slow rotation rates, and find that for several asteroids, the damping timescale is expected to be considerably longer than the age of the solar system, implying that these objects may very well exhibit non-principal axis rotation: wobble, or in extreme cases, the appearance of "tumbling" in space. Perhaps most notable in this group is the asteroid 4179 Toutatis. Both radar observations (Ostro, personal communication) and lightcurve observations (Barucci, Spencer, personal communications) suggest that Toutatis may indeed be in a more complex state of rotational motion than simple principal axis rotation. 1 mention several other examples of objects which might be expected to be in similar states, and a couple examples of lightcurve observations of such objects that appear to support that conclusion.

Tumbling Asteroids

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